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GTRI Project A-5217

Yellow Sea Shallow Water Experiment

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13. ABSTRACT (Maximum 200 words)

The purpose of this grant is to support the acquisition of both oceanographic and acoustic measurements to assesss reverberation and the backscatter from the sea bottom and surface, propagation loss, and the effects of internal wave soutons on acoustic model coupling. The experiment was conducted in late August in the Yellow Sea at 37°N and 124°E.

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Yellow Sea Shallow Water Experiment
August 1996
Final Report

1.0 INTRODUCTION

August - September, 1996 marked the successful accomplishment of a major event for the US and international underwater acoustics community. During this period, the first joint US-China Yellow Sea Shallow Water Acoustic Measurement Program occurred. The US team was composed of research engineers and scientists from the Georgia Institute of Technology (Georgia Tech) and the Applied Physics Laboratory of the University of Washington (APL/UW). The Chinese team was from the Institute of Acoustics, Academia Sinica (IAAS), of the Peoples' Republic of China (PRC), and included the National Acoustics Laboratory in Beijing, Shanghai Acoustics Laboratory, Qingdao Acoustics Laboratory, Qingdao Oceanology University, and the South China Sea Institute of Oceanology in Guangzhou. The measurements were conducted from 21 August to 4 September, 1996 in the northern Yellow Sea between the PRC and North Korea at 37° N and 124°E (figure 1).

Figure 1 Test Site

The primary objective of the joint effort was to measure and characterize the acoustic properties of internal waves. A three-year, three-phase program effort was planned. The first phase was a set of tests to select a site with good internal waves occurring at reasonable intervals, measure and quantify propagation characteristics, reverberation, oceanographic parameters, and bottom characteristics. Phase 2 of the planned effort was to analyze the measured data from the first tests and apply these data to upgrading the shallow water and internal wave analysis and prediction models. A second measurement program would be conducted as Phase 3 to measure detailed characteristics of the internal wave field which could then be analyzed using the advanced models developed during Phase 2.

A second objective of the tests was to collect detailed data on shallow water reverberation along with environmental information on the bottom characteristics and composition, and acoustic information on propagation conditions. These data will enable a much more advanced understanding of reverberation in a shallow water environment, and significantly enhance shallow water reverberation models, especially for broadband, low frequency signals.

The 1996 Yellow Sea measurements successfully accomplished the objectives of the first phase with the selection of a site having internal waves activity throughout the test period. Extensive high quality propagation, reverberation, and ambient noise data were collected along with detailed measurements of oceanographic conditions such as the depth-temperature profile, sound velocity-depth profile, current data, bottom profile, and surface wave height data. Synthetic aperture radar (SAR) data was also obtained from EROS. Representative SAR internal wave data are presented below in Figure 2.

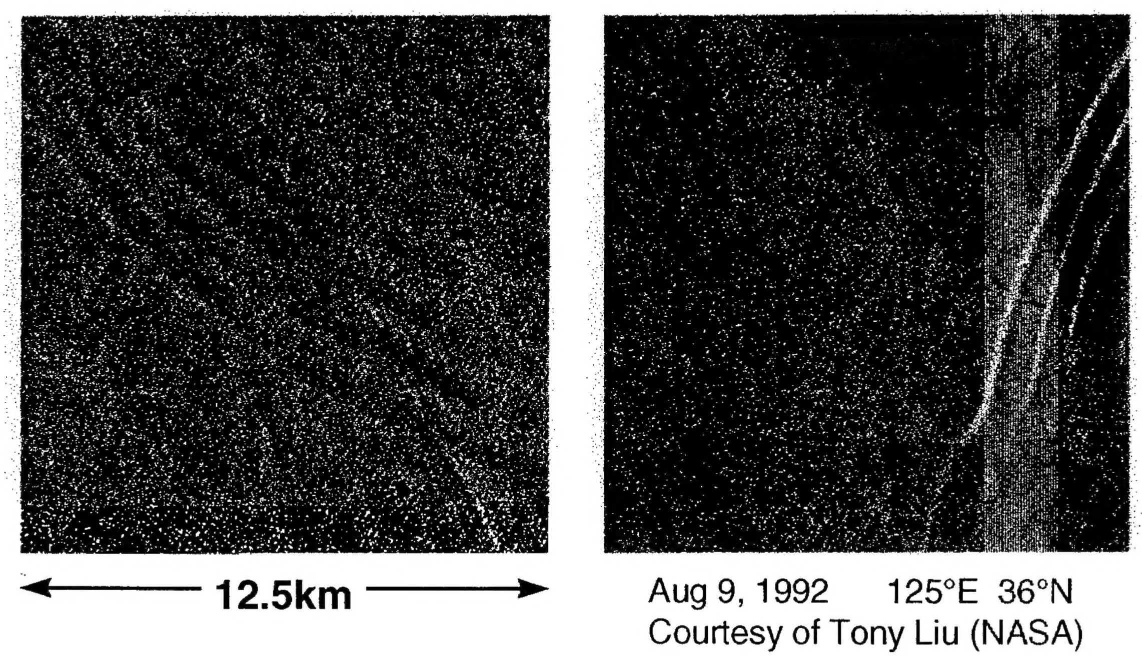


Figure 2 Historical SAR Images of Internal Wave Solitons

At the present time, funding has only been provided for the completion of this first phase. No funds have currently been made available for either the analysis of the first set of data or for the execution of the second measurement effort and the subsequent analysis of those data.

2.0 PROGRAM GOALS AND OBJECTIVES

Program goals and objectives were to accomplish the following:

- Identify potential test sites having measurable internal waves.
- Select a site for the testing.
- Collect detailed propagation loss data to validate the shallow water propagation models and determine the best areas for collecting the internal wave data.
- Collect detailed acoustic and environmental data to include:
    - Temperature-depth profiles over the water column at geometries located in the test site that will allow determination of the passage, magnitude, time, and direction of the internal waves.
    - Propagation loss synchronized with movements of the internal waves within the test area.
    - bottom samples to determine the material composition.
    - bottom slope.
    - sound velocity profiles, current data, and surface wave height data.
- Collect detailed information on reverberation characteristics of the shallow water area sufficient to validate reverberation prediction and analysis models.

3.0 BACKGROUND

Since the late 1980s, researchers at Georgia Tech, Drs. Peter Rogers and Ji-Xun Zhou, collaborated with researchers at the IAAS, led by Professor Renhe Zhang, on several shallow water acoustic problems. These researchers jointly published a number of papers on shallow water topics. Drs. Rogers and Zhou developed several advanced models to predict and analyze the shallow water acoustic phenomena. One of the more critical topics of joint interest was acoustic mode coupling by internal solitons which results in acoustic attenuation significantly greater than that predicted by classical spreading and attenuation. Figure 3 illustrates the relative sound levels verses frequency for two different ranges. Notice the unusual decrease in sound level at 600 Hz. for the longer range propagation. This phenomena is not accounted for by standard attenuation or spreading models. The attenuation is also temporally variable and anisotropic.

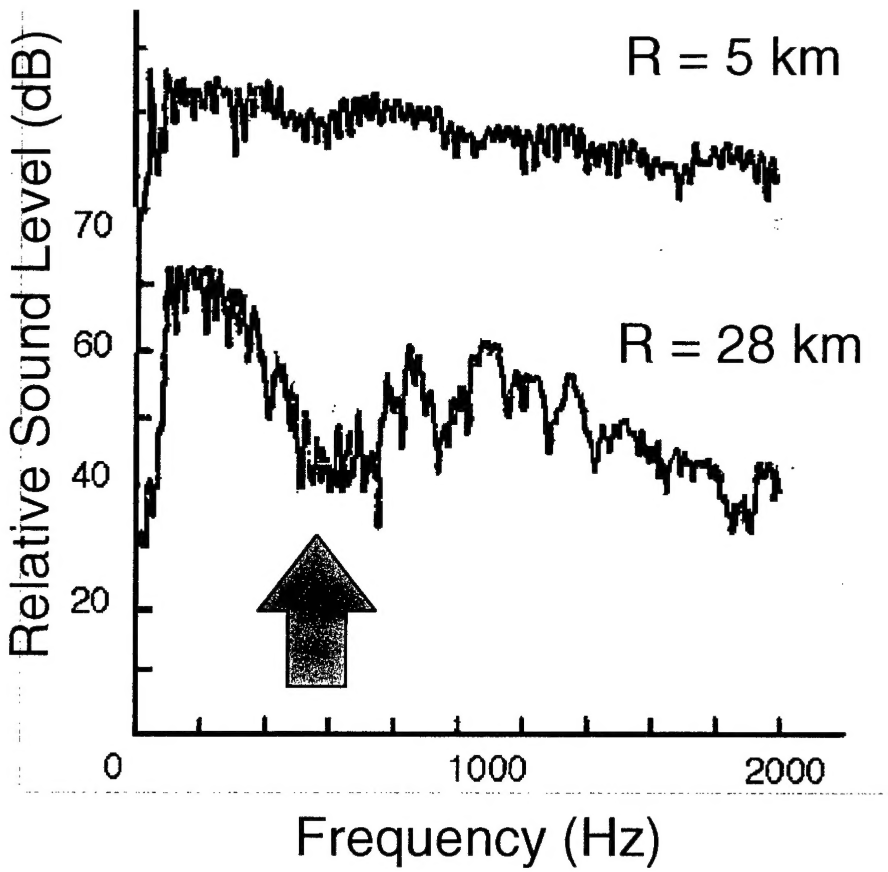


Figure 3

By the mid-1990s, modeling and analysis capabilities had progresses to the state where further advancements required detailed experimental data to verify and validate the models and also to help answer several questions that could only be resolved from actual measurements of the internal wave properties. In 1995, discussions began on the feasibility of conducting a joint measurement program in the Yellow Sea to obtain the needed measured data. The historical sequence of events leading up to this experiment are listed below.

- 1979 -1984 J.X. Zhou *et al* - Institute of Acoustics CAS: Measurements of propagation in Yellow Sea
- 1985 J.X. Zhou relocates to Georgia Tech as visiting scholar
- 1989 J.X. Zhou, X.Z. Zhang & P. H. Rogers first attribute anomalous propagation in Yellow Sea to internal wave interaction.[ASA talks 1989 & 1990; JASA paper 1991, IEEE paper 1993]

- 1989 Zhou funded by ONR to plan Yellow Sea experiment

- June 1989 D. G. Guan, visits Georgia Tech to discuss collaborative research
  This is the first discussion of a cooperative at-sea experiment.

- 1992 Zhou and Rogers present paper on internal wave interaction at Beijing ICA

- 1994 Zhou & Rogers propose joint Yellow Sea experiment to ONR

- March 1995 Zhou, Rogers, Caille and DeFerarri (University of Miami) visit Guangzhou, Beijing and Shanghai to discuss internal wave in the Yellow Sea

- May - June 1995 R. Zhang visits Georgia Tech to plan experiment and write ONR proposal

- October 1995 Joint Chinese-American proposal to ONR for major Yellow Sea internal wave experiment

- December 1995 G. Jin and R. Zhang travel to Georgia Tech for experiment planning meeting

- June 1996 Zhou, Rogers, Caille, Spindel and Dahl visit Beijing for experiment planning meeting

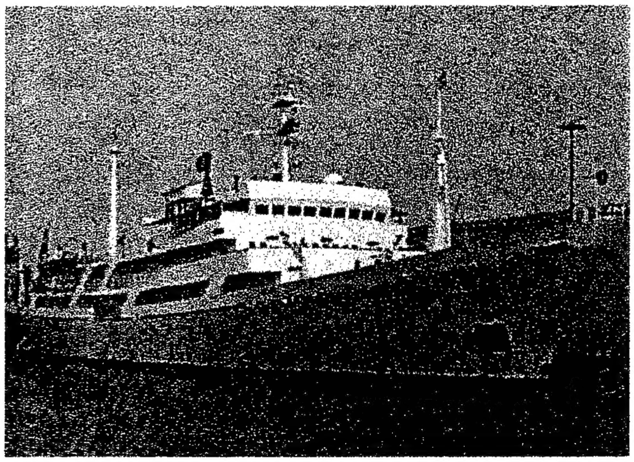
- July 1996 "Modified" Yellow Sea '96 Experiment funded by ONR

- August - September 1996 Yellow Sea '96 Experiment carried out

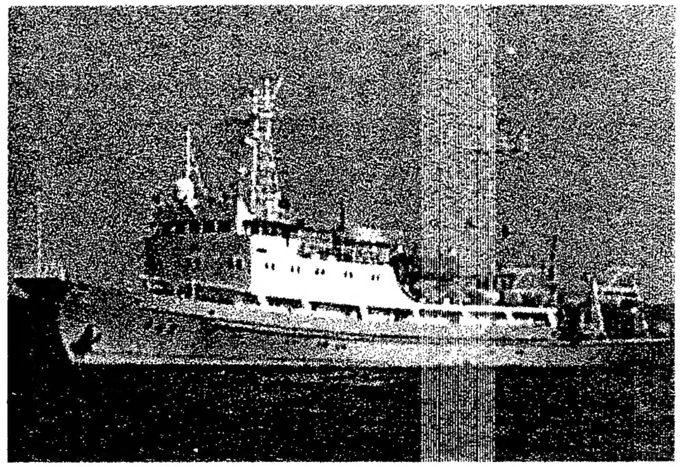
4.0 PLANNING AND TEST PREPARATION

Plans for the measurements were formulated in late 1995 and early 1996. At the same time, a sponsor for the U.S. participation was sought. ONR, Code 31, Dr. Jeffrey Simmen, agreed to sponsor the initial series of tests. Due to the short time between the funding availability and the optimum experiment time, planning focused primarily on using PRC ships and equipment to conduct the actual measurements. The South China Sea Institute of Oceanology from Guangzhou maintains two ocean going research ships, the *Shi Yan 2* and *Shi Yan 3* (Figure 4), that could be provided; these ships were used to conduct the test. PRC equipment to be used during the tests included:

1. two moored acoustic arrays with 16 hydrophones each,
2. one over-the-side acoustic array with 32 hydrophones that would be suspended from one of the research ships,
3. three thermistor chains composed of 16 thermistors each,
4. equipment to measure the sound velocity profile and surface wave height, and
5. transducers for the generation of the acoustic signals.



Shi- Yan 3



Shi-Yan 2

Figure 4 Research Ships from the South China Sea Institute of Oceanology

In evaluating the available equipment, it was determined that two additional acoustic arrays would significantly add to the team's data collection capabilities. APL/UW provided these two additional arrays, a bottom moored 4 element array and a 16 element array to be suspended from the *Shi Yan* 3. The 16 element APL/UW array consisted of equally spaced sensors with a 4 meters spacing and a 2 kHz. sampling rate. The array was also equipped with a tilt sensor and pressure (depth) sensor. PRC also provided a 32 element receive array to be deployed from the *Shi Yan* 3. The two basic bottom moored array configurations are illustrated in Figure 5. PRC provided three modulatable sources with resonances at 200 Hz., 400 Hz., and 900 Hz. In addition PRC also provided two types of explosive sources with approximately 38 g and 1 kg TNT explosive weights. These wideband sources were time fused. It was also felt that an additional low frequency source was required. Georgia Tech was tasked to obtain a J15-3 transducer from the Underwater Sound Reference Division, Naval Underwater Warfare Center (USRD/NUWC). Georgia Tech provided thermistors that could be attached to the APL/UW and PRC over-the-side arrays to measure temperature data at these arrays. Identification of the possible test sites was a key element of the planning process. Satellite synthetic aperture radar (SAR) imagery from EROS 1 and 2 were purchased and analyzed for potential areas to determine the existence of internal waves and their direction of propagation in the Yellow Sea at that time of the year.

In late June 1996, Georgia Tech and APL/UW members of the US team traveled to Beijing, PRC to meet with the PRC researchers to finalize the planning and formalize the US-PRC agreements. Throughout July, activities focused on acquiring the equipment to be provided by Georgia Tech, packaging the equipment for shipment to the PRC, and getting the necessary approvals, shipping, and travel documents processed. The U.S.

portion of the funding for the ships was handled via purchase order from Georgia Tech to the National Laboratory of Acoustics in Beijing. On August 19, the team assembled in Qingdao to load the two research ships and install the equipment for the tests.

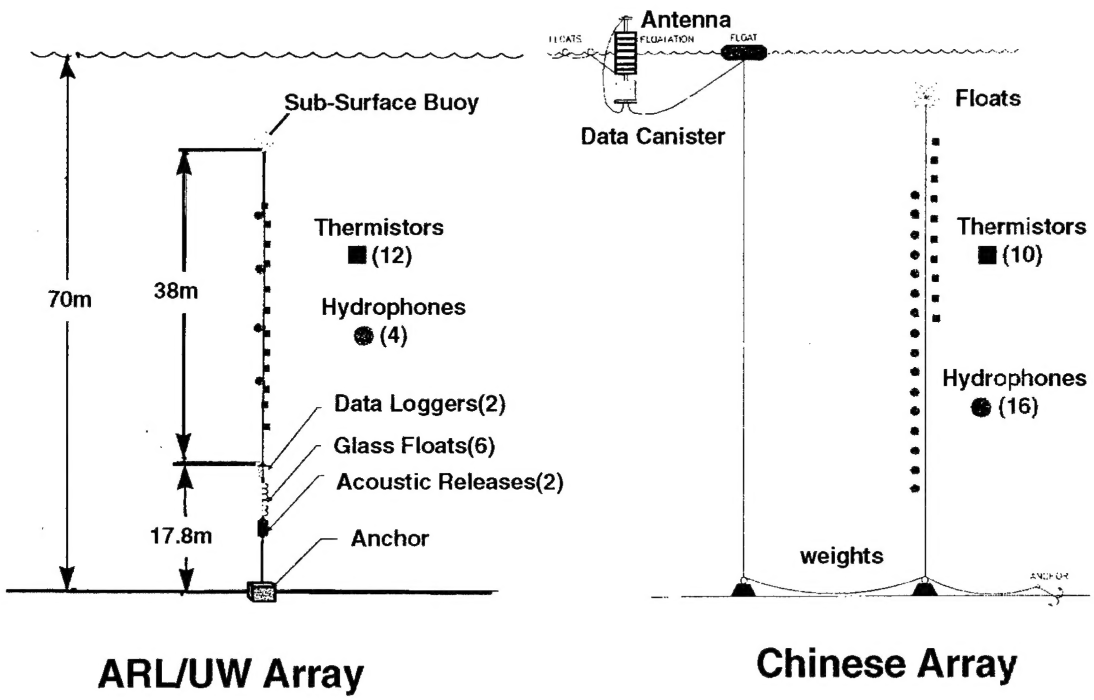


Figure 5 Bottom Moored Arrays

5. Summary of Experiments:

This experiment consisted of two phases, with the first being a reverberation and propagation experiment and the second an internal wave/acoustic interaction experiment. The original site selected was 126°E and 36° N. The *Shi Yan 2* conducted a pre-experiment site survey while transiting from Guangzhou to Qingdao. The purpose of the pre-experiment site survey was to obtain bottom cores, SVPs, and to look for internal solitons by measuring the thermocline depth using a side scan sonar over a large transit distance. It was thought the solitons could be seen as layer depth variations. After review of the data in Qingdao, it was determined that no internal wave activity existed at this location. The experiment test site was then moved to 124°E and 37°N.

The actual experiment conduct consisted of three deployments with the first being related to phase 1; the second deployment was aborted shortly after the start due to equipment failure; and a third deployment for the internal wave effects.

In the first deployment, the *Shi Yan 3* would serve as the main receive platform from which the PRC 32 element array and the APL/UW 16 element array would be suspended. The moored array deployment plan is illustrated in figure 6. One PRC satellite buoy array was deployed 2 km north of the *Shi Yan 3,* and the PRC radio buoy array was deployed 2 km west of the *Shi Yan 3.* The APL/UW moored array was deployed

approximately 9 km 315°T from the *Shi Yan 3*. The thermistor arrays were deployed 1 km east and 1 km south of the *Shi Yan 3*. The *Shi Yan 2* then progressed along the track detailed in figure 6. Reverberation measurements were made from the *Shi Yan 3* using explosive charges as summarized below. The *Shi Yan 2* also positioned herself approximately 5 kms to the west of the *Shi Yan 3* and transmitted using the J15-3 and spark source.

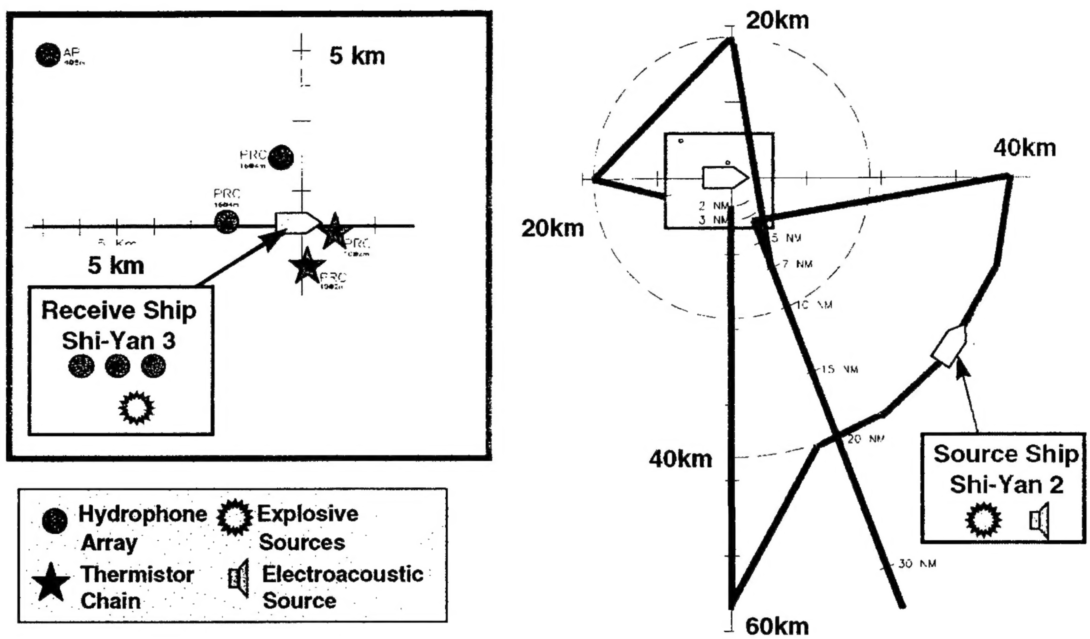


Figure 6 Phase 1array configuration and experiment track

The second deployment was to study internal wave effects. Unfortunately the *Shi Yan 3* lost her sea anchor during recovery from the first deployment sequence. This resulted in a significantly smaller anchor being used afterwards. The APL/UW deployed array was unavailable for this evolution due to failed hydrophones. Overall, this deployment is considered a complete failure because: 1. one PRC satellite array system failed completely; 2. the second PRC satellite array system had a gain error which resulted in under gaining the signal (it was determined that the arrays were strumming and had no high pass filters; subsequently the team immediately added anti-strumming streamers to one array and installed high pass filters to the other array); and 3. the ship's anchor did not hold resulting in significant drift.

The third deployment was also an internal wave experiment. The objective was to determine the acoustic mode coupling effects of the internal solitons. Dr. John Apel reviewed SAR data from earlier in August and determined the solitons were traveling from east to west with the length of the wave train estimated to be several kilometers. The approach was to deploy the PRC satellite arrays along the propagation path and have the *Shi Yan 3* serve as the source boat to the east of the arrays. The APL/UW deployed array was repaired and deployed at a right angle to the propagation path. Deployed

thermistors chains were situated in a triangle near a PRC array with clip-on thermistors. With this setup, the propagation could be measured between the two PRC satellite arrays with and without the soliton present. The array configuration is illustrated in figure 7.

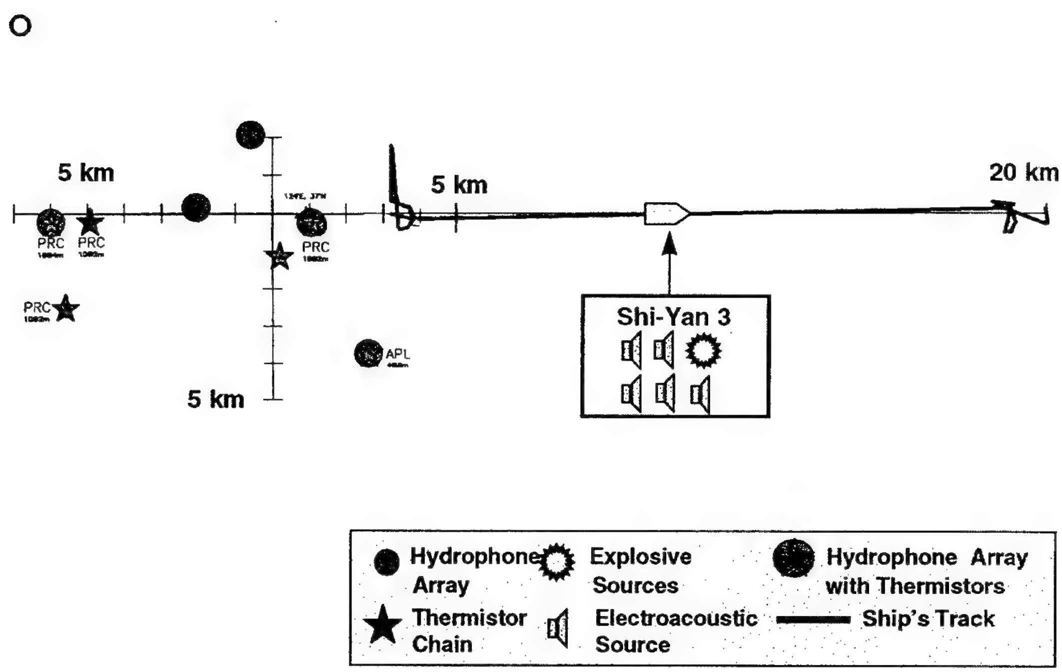


Figure 7 Phase 3 Array configuration and experiment track

DEPLOYMENT ONE SUMMARY:

Measurement Objectives: acoustic transmission loss
modal propagation
reverberation

Receivers and status:

PRC 32-element array on Shi-Yan 3: successful

PRC 16-element moored array Radio Buoy: lost at sea

PRC 16-element moored array Satellite Buoy I: total failure of acquisition system

APL 04-element moored array: total failure of acquisition system

APL 16-element array on Shi-Yan 3: successful

Two Thermistor arrays: successful

Wideband sources

H7 - nominal depth of detonation is 7m
H50 - nominal depth of detonation is 50m
38gm - beer bottle sized explosive
1kg - champagne bottle sized explosive

22Aug96

Source Range: 0.1-1nm
Source Type: H7/H50 38gm
Casting Interval: 1 min
Events: 10

Source Range: 1.2-3nm
Source Type: H7/H50 38gm
Casting Interval: 2 min
Events: 10

Source Range: 3.3-6nm
Source Type: H7/H50 38gm
Casting Interval: 3 min
Events: 10

Source Range: 6nm
Source Type: H50 38gm
Casting Interval: 10 sec
Events: 10

Source Range: 6.4-10nm
Source Type: H7/H50 38gm
Casting Interval: 4 min
Events: 10

Source Range: 10nm
Source Type: H50 38gm

Casting Interval: 10 sec
Events: 10

Source Range: 15nm
Source Type: H50 38gm
Casting Interval: 10 sec
Events: 10

23Aug96

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 10 sec
Events: 10

Source Range: 30nm
Source Type: H50 38gm
Casting Interval: 10 sec
Events: 10

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 6
Source Position: Point 1 (36°40.98'N/124°07.75'E)

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: Point 2 (36°43.85'N/124°14.72'E)

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: Point 3 (36°48.25'N/124°20.23'E)

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: Point 4 (36°53.85'N/124°23.82'E)

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5

Source Position: Point C (37°00.09'N/124°25.08'E)

Source Range: 1nm
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 10
Source Position: (36°56.99'N/124°02.013'E)

Source Range: 2nm (2.12 as measured by radar)
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 10
Source Position: (36°56.99'N/124°02.013'E)

Source Range: 3nm (3.12 as measured by radar)
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 10
Source Position: (36°55.45'N/124°02.78'E)

Source Range: 5nm (5.10 as measured by radar)
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 10
Source Position: (36°53.65'N/124°03.73'E)

Source Range: 7nm (6.90 as measured by radar)
Source Type: H7/H50 38mg
Casting Interval: 5 sec
Events: 10
Source Position: (36°51.86'N/124°04.56'E)

Source Range: 10nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: (36°48.93'N/124°05.95'E)

Source Range: 15nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: (36°44.24'N/124°08.21'E)

Source Range: 20nm
Source Type: H50 38gm
Casting Interval: 5 sec

Events: 5
Source Position: (36°39.72'N/124°10.43'E)

24Aug96

Source Range: 30nm
Source Type: H50 38gm
Casting Interval: 5 sec
Events: 5
Source Position: (36°29.96'N/124°15.05'E)

Electric Spark Source

Source Range: 5nm
Source Depth: 25 meters
Spark Interval: 8 seconds

Source Range: 3nm
Source Depth: 25 meters
Spark Interval: 8 seconds

Source Range: 5nm
Source Depth: 25 meters
Spark Interval: 8 seconds

Wideband sources (H7/H50)

Source Range: 10nm
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 8
Source Position: (37°10.03'N/124°00.12'E)

Source Range: 10nm
Source Type: H7/H50 38gm
Casting Interval: 5 sec
Events: 7
Source Position: (37°00.08'N/123°47.54'E)

Composed Sources

Source Range: ??
Source Mode: see Fig. 5
Source Depth: 40 meters
Event Duration: 12 hours
Source Position: (36°58.76'N/123°54.06'N)

25Aug96

WideBand Sources

Source Range: 0nm		
Source Type: H7		38gm
Events:	15	
Source Position:		

Source Range: 0nm		
Source Type: H25		38gm
Events:	10	
Source Position:		

Source Range: 0nm		
Source Type: H50		38gm
Events:	10	
Source Position:		

Source Range: 0nm		
Source Type: H50		1kg
Events:	5	
Source Position:		

Source Range: 0nm		
Source Type: H7		1kg
Events:	5	
Source Position:		

<u>DEPLOYMENT TWO SUMMARY</u>:

Measurement Objectives: effect of internal waves on acoustic transmission

Receivers and status:

PRC 16-element moored array Satellite Buoy I (far array): total failure of acquisition system

PRC 16-element moored array Satellite Buoy II (near array): partial failure of acquisition system - gains set too low so (there are only 2 to 3 bits of information per sample)

APL 04-element moored array: under repair

<u>DEPLOYMENT THREE SUMMARY</u>:

Measurement Objectives: effect of internal waves on acoustic transmission

Receivers and status:

PRC 32-element array on Shi-Yan 3: successful

PRC 16-element moored array Satellite Buoy I (far array): successful

PRC 16-element moored array Satellite Buoy II (near array): successful

APL 16-element array on Shi-Yan: successful

APL 04-element moored array: partially successful: failure of acquisition system for hydrophones 3 and 4.

30Aug96

Composed Sources

Source Range: ??
Source Mode: see Fig. 5
Source Depth: 40 meters
Event Duration: 5 min
Source Position: (36°58.85'N/123°54.51'N)

Wideband Sources

Source Range: 0nm
Source Type: H7 1kg
Source Range: 71nm

Events: 5

Source Range: 0nm
Source Type: H50 1kg
Source Range: 71nm
Events: 5

Composed Sources

Source Range:
Source Mode: CW 290Hz See Fig. 6
Source Depth: 50 meters
Repetition Cycle: 5 min
Event Duration: 30 min
Source Position:

Source Range:
Source Mode: CW 290Hz See Fig. 6
Source Depth: 50 meters
Repetition Cycle: 1 min
Event Duration: 15 min
Source Position:

Composed Sources and Wideband Sources

Source Range:
CW Source Mode: See Fig. 10a
CW Source Depth: 50 meters
WB Source Type: H7 38gm
WB-Vertical Array separation: 73m
Casting Interval: 5 min
Event Duration: 3.5 hrs
Source Position:

31Aug96

Source Range:
CW Source Mode: See Fig. 10b
CW Source Depth: 50 meters
WB Source Type: H50 38gm
WB-Vertical Array separation: 73m
Casting Interval: 10 min
Event Duration: 6 hrs
Source Position:

Source Range:
CW Source Mode: See Fig. 10b
CW Source Depth: 50 meters
WB Source Type: H7 38gm
WB-Vertical Array separation: 73m
Casting Interval: 10 min
Event Duration: 1 hrs
Source Position:

Source Range:
CW Source Mode: See Fig. 10b
CW Source Depth: 50 meters
WB Source Type: H50 1kg
WB-Vertical Array separation: Cast from end of ship
Casting Interval: 10 min
Event Duration: 1.5 hrs
Source Position:

6. Problems and Recommendations for Improvement

Virtually all problems encountered during the YSIWAMP 1 experiment can trace their origin to the lack of detailed pre-experiment planning and testing. This inadequate preparation was due to the fact that funding was not made available to conduct the experiment until literally the last minute. Normally, an experiment would be delayed when these circumstances arise. However, in order to capitalize on optimal environmental conditions in the Yellow Sea, the test had to be conducted during the last week of August 1996 (or be delayed one full year). Consequently, there was insufficient time to address many of the details associated with such an undertaking. The result was a host of small problems that were a constant drain on the researchers' time and effort.

Pre-experiment planning was also hindered by communication difficulties. Specifically, there was a 12-hour time differential between Beijing and Atlanta. This meant that telephone conversations were, at best, inconvenient. In addition, facsimile transmissions were not always reliable, and electronic mail messages were surprisingly slow. The combined result was that routine correspondence often had a turn-around time of up to four days.

The short preparation time prevented adequate pre-experiment testing from occurring. Specifically, the APL/UW moored array had 50% hydrophone failures. They were not able to test their deployable array in water prior to the first deployment of the experiment. A second hardware design problem, namely no high pass filtering on the PRC arrays was later discovered when stumming caused clipping of the preamplifiers. Both problems would have been discovered and fixed prior to the experiment. The shipping of equipment from the U. S. to the PRC took longer than expected, resulting in equipment arriving at the pier several hours prior to the underway; again there was no time for proper testing. The electrical system on the *Shi Yan 3* was inconsistent resulting in lost time at sea establishing a common electrical ground.

The *Shi Yan 3* was not designed to handle heavy lifts. Manhandling the APL/UW array was difficult. The lack of lift capability resulted in light anchors for the moored arrays and subsequently very small buoyant floats; the consequences were arrays that did not maintain verticality. If sufficient time and money had been available for procurement, acoustic releases could have been used which would have mitigated this problem. The *Shi Yan 3* was not capable of making a two point moor, which prevented putting the J15/3 on the bottom for fluctuation measurements. Finally, anchoring the *Shi Yan 3* in 70 meters of water was more difficult than anticipated.

Once on the ships, there was no alternative but to use English as the official language of the experiment because the U. S. researchers spoke no Chinese. Unfortunately the Chinese's ability to speak English was not consistent, and only one person of those aboard either ship could have been considered to be fluent in both English and Chinese. Furthermore, the Chinese had communication difficulties amongst themselves because the researchers mostly spoke Mandarin and the crew Cantonese.

Another source of problems was the fact that the Chinese seemed to have no established chain of command for the utilization of their experimental hardware. This made planning difficult because it was not always obvious who should attend a planning

meeting. Furthermore, once a plan had been formulated, there was either no effective means by which it could be communicated or the authority of the plan was not recognized.

As previously stated, virtually all of these problem could have been avoided, or at least minimized, had there been sufficient time for detailed pre-experiment planning. However, future experiments could benefit greatly if at least one person fluent in both spoken and written English and Mandarin Chinese could be retained to assist the U. S. researchers in the planning and execution of the tests.

Despite all of these problems, a successful experiment took place and the data appears to be of good quality. Much of the credit goes to the participants and their desire to be successful. The participants include not only the scientists from both the U. S. and PRC teams, but their respective management organizations, the ONR contracting office, and the crews of both ships. Representative data are illustrated in the invited paper presented at the International Conference on Shallow Water Acoustics, Beijing, Peoples' Republic of China, April 1997 and is included as Appendix C.

Appendix A

HYDROPHONE CHARACTERISTICS

PRC 32-element over-the-side array on Shi-Yan 3

2m element separation
6kHz and 12kHz sampling rate
tilt sensor sampled a 1Hz
PRC 16-element moored array Satellite Buoy I (far array)
4m element separation
1500Hz sampling rate
10kHz sampling rate

PRC 16-element moored array Satellite Buoy II (near array)
2m element separation
1500Hz sampling rate
10kHz sampling rate
APL 16-element over-the-side array on Shi-Yan 3
4m element separation
2kHz sampling rate
tilt and pressure sensor sampled at 10Hz
APL 4-element moored subsurface array
8m element separation
2kHz sampling rate

THERMISTER CHARACTERISTICS

Satellite Array #1

16 hydrophones, 4 meter spacing, first hydrophone at 5 meters

13 thermistors, various spacing to maximize thermocline coverage

DEPTH (m)	ITEM
0	surface and satellite can
3	flotation balls
6	thermistor 01
10	thermistor 02
12.5	thermistor 03
16	thermistor 04
19	thermistor 05
22	thermistor 06
24.5	thermistor 07

28	thermistor 08
31	thermistor 09
34	thermistor 10
36.5	thermistor 11
40	thermistor 12
55	thermistor 13
71	anchor bottom

Ship Mounted Thermistor Array

11 thermistors, 5 meter spacing, first element at 2 meters deep

Deployed Thermistor Array #2

10 thermistors, 2 meter spacing, first element at 5 meters deep

Appendix B

SUMMARY OF OCEANOGRAPHIC DATA AVAILABLE

note all times listed are in Peoples Republic of China Time

Global Positioning System log for the Shi Yan 3:

latitude and longitude
(approximately 20 sec intervals)

Global Positioning System log for the Shi Yan 2:

latitude and longitude
(10 sec intervals)

from	8/22/96	11:17	through	8/23/96	09:02
from	8/23/96	21:44	through	8/24/96	00:05
from	8/24/96	08:51	through	8/25/96	02:22

Depth Log:

depth, latitude, and longitude
(2 sec interval)

from	8/31/96	11:00	through	8/31/96	11:30
from	8/31/96	12:20	through	8/31/96	12:38
from	8/31/96	13:22	through	8/31/96	13:42
from	8/31/96	14:20	through	8/31/96	14:30
from	8/31/96	14:50	through	8/31/96	15:08

Current Profile Log:

Current velocity, SHI YAN 3 velocity, depth, latitude, and longitude

(3 minute intervals)

from	8/22/96	13:56	through	8/31/96	11:25

Global Positioning System data SHI YAN 3
latitude and longitude
(3 minute intervals, with several gaps)

from	8/22/96	13:53	through	8/31/96	12:34

Sound Speed, Temperature, and Depth (CTD):

temperature, salinity, density, latitude, longitude, and depth
(1 hour intervals when possible, 125 data sets)

from	8/22/96	15:53	through	8/31/96	09:00

Weather Data

latitude, longitude, wind speed, wind direction, dry bulb temp, wet bulb temp, pressure, visibility, and cloud cover.

(3 hour intervals)

from	8/22/96	08:00	through	8/31/96	14:00

Wave Data:

surface wave direction and height, mean and raw
(1 hour intervals when possible, 93 data sets)

from	8/22/96	17:00	through	8/29/96	12:57

Temperature Profile:

temperature and depth
(1 minute intervals)

from	8/22/96	18:29	through	8/25/96	11:15
from	8/27/96	22:46	through	8/29/96	13:26
from	8/30/96	03:20	through	8/31/96	09:39

Temperature Profile:

temperature
(1 minute intervals)

from	8/22/96	4:52	through	8/25/96	16:00

Temperature Profile:

temperature
(1 minute intervals)

from	8/22/96	4:52	through	8/25/96	15:00

Temperature Profile:

temperature
(30 second interval)

satellite #1 deployment A

from	8/22/96	10:16	through	8/25/96	14:34

APL	deployment A				
from	8/22/96	13:50	through	8/27/96	06:53
satellite #1	deployment B				
from	8/27/96	10:30	through	8/29/96	16:00
satellite #2	deployment B				
from	8/27/96	13:45	through	8/29/96	17:05
APL	deployment C				
from	8/29/96	19:20	through	8/31/96	11:49
satellite #1	deployment C				
from	8/30/96	00:41	through	8/31/96	14:00
satellite #2	deployment C				
from	8/30/96	01:35	through	8/31/96	13:13

Appendix C

Paper Presented at the International Conference on Shallow Water Acoustics, Beijing, Peoples' Republic of China, April 1997

OVERVIEW OF THE JOINT CHINA-U.S. "YELLOW SEA '96" EXPERIMENT

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ABSTRACT

Simultaneous observations of internal wave activity and acoustic wave propagation in 70 m water in the Yellow Sea were made in the late summer of 1996. The primary objective of this experiment was to validate the predicated modal coupling, fluctuations and alterations in propagation loss induced by shallow-water internal waves and particularly internal wave solitons. The Yellow Sea, which is known to have significant internal wave activity in the summer, provides an ideal environment for such research because it has a very flat and homogeneous bottom and a very strong, sharp thermocline, often with temperature differences exceeding 15° occurring over just a few meters of depth. The environment lends itself to relatively simple models for both the acoustic field (a two layer Pekeris model) and the internal wave field (a two layer fluid model) hence simplifying the interpretation of the internal wave - acoustic wave interactions. Propagation was measured over distances up to 55 km using narrow band and broad band electroacoustic and explosives sources detonated both above and below the thermocline, over the frequency range of 50 Hz to 5 kHz. The receivers were three moored and two suspended hydrophone arrays, some of which spanned the water column. Internal wave activity was monitored using several moored and suspended thermistor chains as well as by using SAR satellite imagery, and high frequency sonar. Propagation data was taken as a function of range, as a function of time at a fixed range and as a function of azimuth. Measurements were made over a complete tidal cycle in order to obtain acoustic data in the presence differing levels of internal wave activity. Supporting environmental data obtained during the experiment includes ADCP, bottom profile and surface wave-height spectra and bottom coring. Long range acoustic reverberation data was also acquired and will be used, along with the propagation data, to obtain bottom parameters by inversion. This paper will provide an overview of Yellow Sea '96 experiment and will show some representative preliminary results. More detailed results will be presented by individual investigators in other papers presented at this conference.

Yellow Sea '96 was the first joint Chinese-American underwater acoustics experiment in history. The institutional participants in the experiment included National Acoustics Laboratory, the Shanghai Acoustics Laboratory and the Qingdao Acoustics Laboratory, and other components of the Institute of Acoustics (IoA) of the Chinese Academy of Sciences, the South China Sea Institute of Oceanology and the Ocean University of Qingdao, the Georgia Institute of Technology and the Applied Physics Laboratory of the University of Washington. In addition to the authors of this paper, other participants in the experiment included: ZHU Houqing, CAI Xiaoyang, HAO Longsheng, WANG Futang, LI Pin, LI Xilu, QIU Xinfang, LI Zhengkun, QIAN Bingxing, YAN Jin, JIANG Xiaoyong, FENG Xiqiang, MA Lei, ZHOU Shihong, YIN Ye, Huang Qizhou, CHEN Rongyu, LU Bo, CHEN Hanquan, LUO Wenyu, WU Lixing, GONG Zaixiao and ZHAO Hong of the Peoples' Republic of China and George McCall, Jim Martin, Russ Light, Brad Libby, Tom Willet and Duane Tate of the United States. The experiment was jointly funded by the U.S. Office of Naval Research and the Chinese Academy of Sciences.

The scientific genesis for Yellow Sea '96 was Zhou's discovery of the "Summer Effect" in the Yellow Sea. What Zhou observed was an anomalously high propagation loss in certain frequency bands. Data typical of this effect is shown in Fig. 1a, which shows predicted and measured pressure at a range of 28 km from the source . The anomalously high attenuation around 600 Hz is evident. The excess attenuation, which often exceeds 20 dB was found to be seasonal (occurring only in the summer) highly anisotropic and temporally variable. These properties lead Zhou, Zhang and Rogers[1] , to suspect that internal waves caused the "Summer Effect". They hypothesized that internal wave solitons coupled energy from lower to higher order acoustic modes. The higher attenuation was due to the fact that these higher modes are much lossier than the lower modes. The frequency selectivity of the effect was hypothesized to be due to the relatively narrow bandwidth of soliton packets

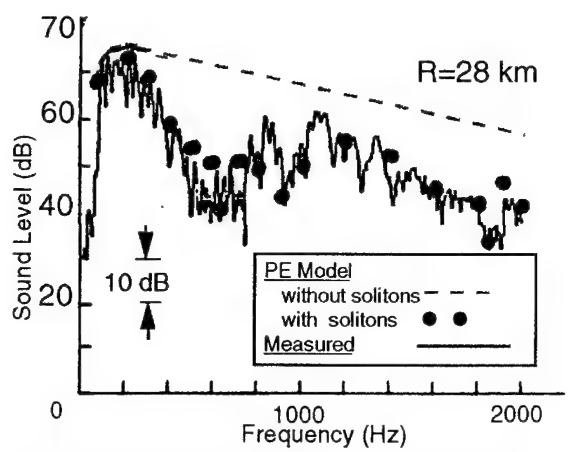

Fig.1a Measured and modeled SPL 28 km from

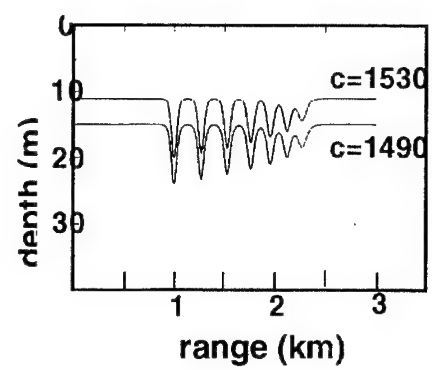

Fig.1b Internal wave soliton packet assumed in PE model

which only couple modes whose wavenumbers differ by the soliton wavenumber ($k_{iw} = k_m$-

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[1] Zhou, J.X., Zhang, X.Z. and Rogers, P.H. "*Resonant interaction of a sound wave with internal solitons in the coastal zone*" J. Acoust. Soc. Am. **90**, 2042-2054 (1991).

k_n). Zhou, Zhang and Rogers[2] used a PE model to demonstrate that an internal wave packet such as that shown in Fig. 1b located between the source and the receiver could explain the effect (the solid circles in Fig. 1a). Although internal wave solitons are known to be present in the Yellow Sea (Fig 2a) there were no concurrent measurements of internal waves when Zhou's acoustic data was taken. A new experiment, with extensive, concurrent oceanographic observations, would be required to directly validate the internal wave interaction hypothesis. Yellow Sea '96, was a preliminary attempt at such an experiment.

The Yellow Sea is, in many ways an ideal location for studying the interaction of sound with internal waves. The bottom is very flat (depth constant to within ± 1 m over a 100 square mile area) and homogeneous. This is important because, like internal waves, bottom variation can induce modal coupling. The thermocline is extremely sharp with often as much as a 10°C change over a meter or two change in depth.(see Fig 2a). This simplifies the both the acoustic and the internal wave modeling since the fluid is essentially just a two layer system. Finally, the area is known to have vigorous internal wave activity in the

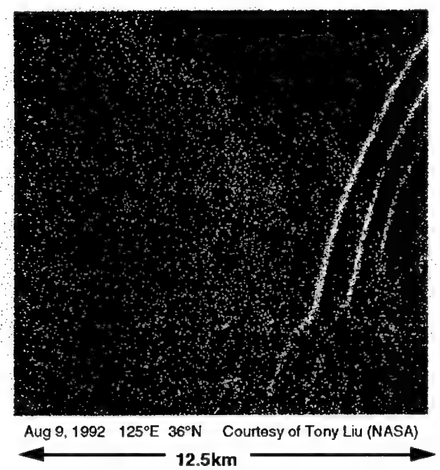

Fig. 2a Satellite image of internal waves in the Yellow Sea

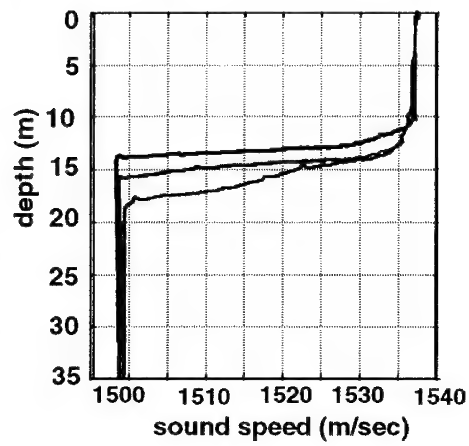

Fig. 2b Sound speed profiles in the Yellow Sea showing strong thermocline

latesummer. The principal technical objective of the experiment was to study the effect of internal waves on acoustic propagation. This included modal coupling due to interaction with solitary internal wave packets and the resulting excess attenuation (the "Summer Effect") as well as observations of internal wave induced amplitude and arrival time fluctuations[3]. Secondary objectives included general measurements of the acoustics of the Yellow Sea including noise, reverberation, propagation and coherence. Measurements taken during the experiment included general oceanographic data including CTD, SVP, wave height, bottom profile and cores as well as extensive measurements with thermistor chains directed at characterizing the internal wave field. Acoustic propagation measurements were made at

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[2] Zhou, J.X., Zhang, X.Z., Rogers, P.H., Wang, D.Z. and Luo, E.S. "*Anomalous sound propagation in shallow water due to internal wave solitons,*"IEEE Proc. OCEANS '93, **1**, 87-92 (1993)

[3] Zhou, J.X., Zhang, X.Z. and Rogers, P.H. "*Modal characteristics of acoustic signal fluctuation induced by shallow water internal waves.*" IEEE Proc. OCEANS '96, **1**, 1-8 (1996)

extremes of the tidal cycles to provide data both with and without internal wave activity. Acoustic measurements were made with moored and suspended vertical arrays to permit estimation of the modal structure of the acoustic field. Explosives (38g to 1 kg TNT), a broad band electrodynamic projector (USRD J15-3) and several high power narrow band Chinese and Russian made PZT projectors were used as sound sources. Transmitted signals included M-sequences, FM chirps and CW (110, 210, 290 and 420 Hz). Measurements were made with sources both above and below the thermocline.

The experiment test site for Yellow Sea '96 is shown in Fig. 3a. (It is not the site of Zhou's original experiments.) The water depth was 70m and the bottom was flat.

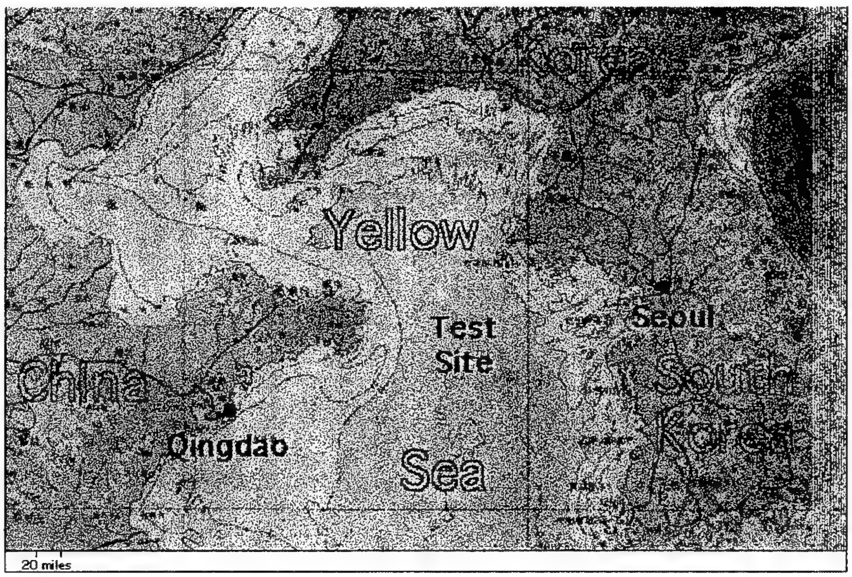


Fig. 3 Test Site location for Yellow Sea '96

Two ships, the Shi-Yan 2 (source ship) and Shi-Yan 3 (receiver ship), were used in the experiment (Fig. 3b). Ships and crew were from the South China Sea Institute of Oceanography in Guangzhou. There were three 16 element moored vertical arrays provided by the Institute of Acoustics and a four element.

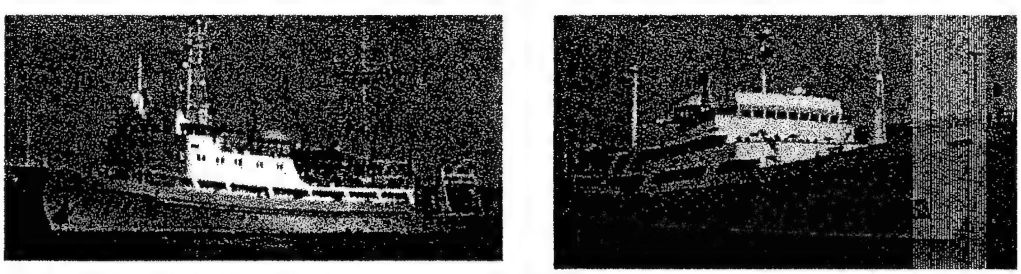
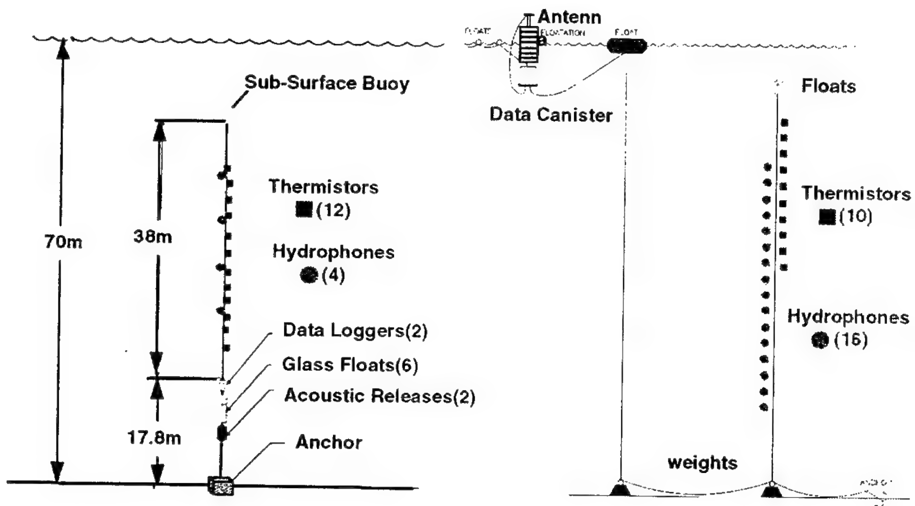


Fig. 3b *Shi Yan 2*and *Shi Yan 3*

array provided by APL/UW (see Fig. 4). All acoustic moorings were outfitted with self recording thermistors. There was also a 32 element suspended array (IoA) and a 16 element suspended array (APL/UW).

Some observed temperature-depth plots, indicating the steep thermocline and strong variability and are shown in Fig. 5a. An isothermal depth vs time plot derived from a themistor chain suspended from the Shi-Yan 3 indicating an apparent soliton-like event is



shown

Fig.4 Array configuration: APL/UW array on left and Chinese array on right

in Fig 5b. The amplitude of the disturbance is over 15m. The increasing amplitude of the solitons (as opposed to the decreasing amplitude typical of soliton packets) is somewhat puzzling.

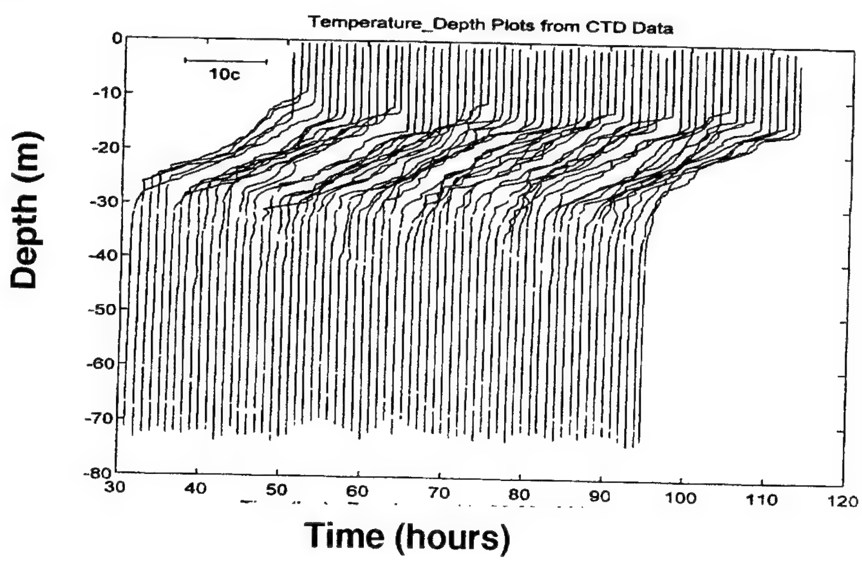


Fig. 5a Variability in observed temp depth profiles

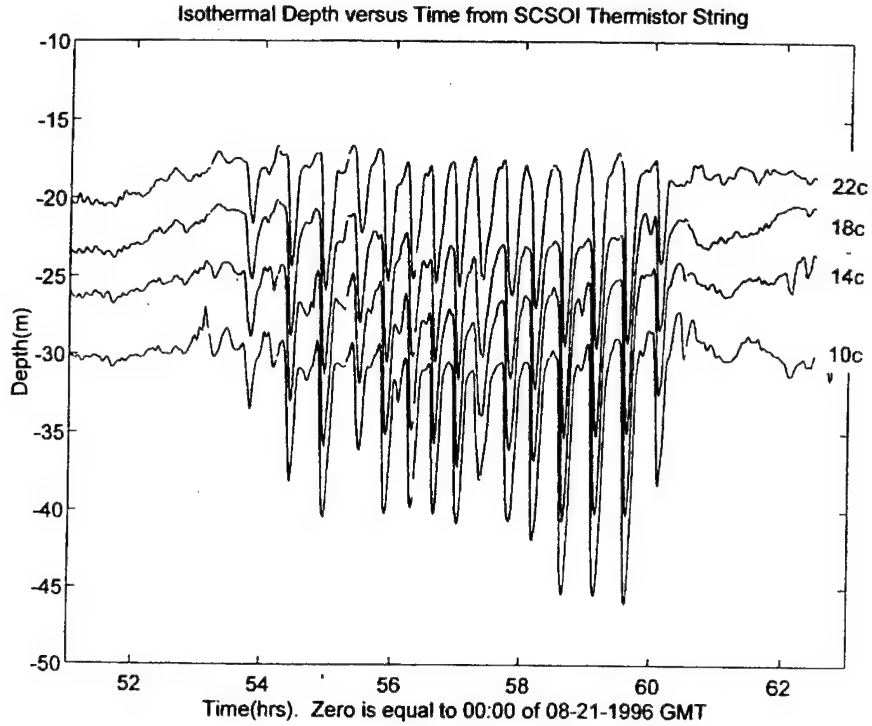


Fig. 5b Observed internal wave "event"

Array positions and ship tracks for the first and third array deployments are shown in Fig. 6. In the first deployment (Fig 6a) propagation was measured as a function of range in three directions and as a function of azimuthal direction for a fixed range of 20 km. Measurements were made with both the moored arrays and arrays suspended from the Shi-Yan 3. Reverberation data was also acquired in this configuration. The third deployment (Fig. 6b) was more directed at observing internal wave effects. The experiment was aligned with what was believed (from satellite observations) to be the predominant direction of internal wave propagation and the Shi-Yan 3 (now the source ship) followed a radial in this direction for the propagation measurements. Data was also taken in both deployments over long periods of time (up to 24 hours) with fixed sources and receivers to measure fluctuations and to identify possible coupling events from variations in mean propagation loss or modal composition.

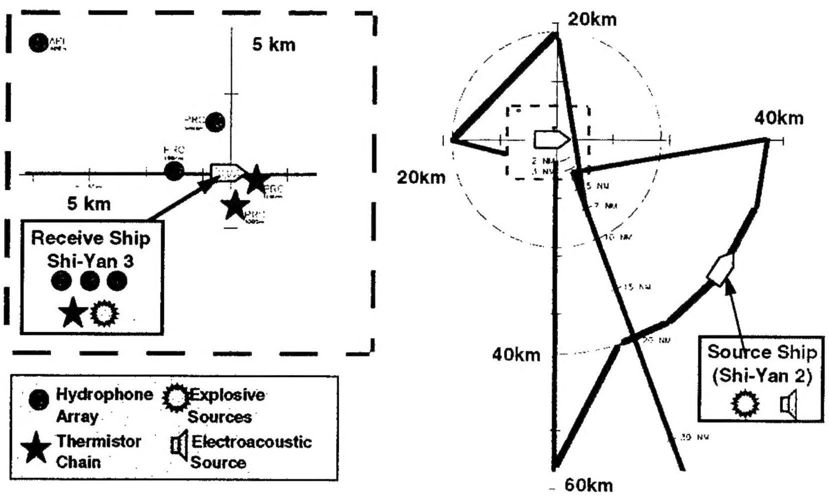


Fig. 6a Deployment of assets for propagation and reverberation experiments

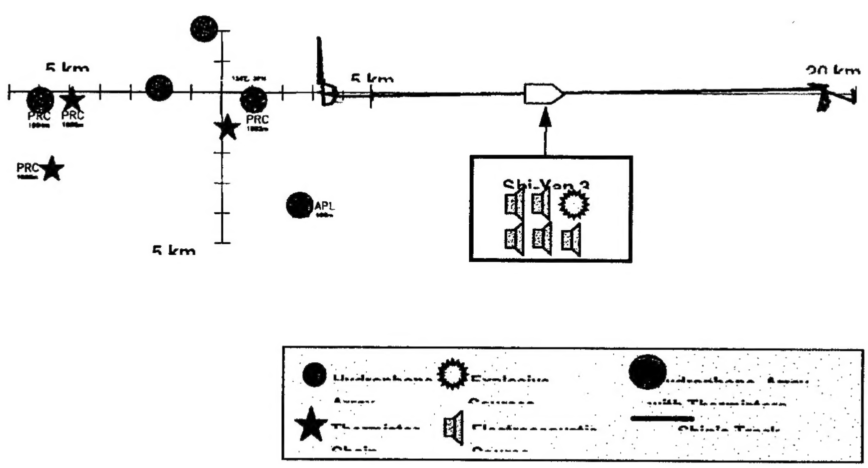


Fig. 6b Deployment of assets for internal wave effects experiment

Representative acoustic data is shown in Figs 7 - 9, indicate the quality of the data taken during the experiment. Figure 7a shows low frequency reverberation data [taken by Dahl and Light APL/UW] for two different source/receiver depths. Note that the reverberation is higher for the shallower source/receiver pair. Figure 7b shows high frequency reverberation data [taken by Jin IoA] which shows the opposite trend.

Figure 8 shows arrival structure for explosive shots (including shock and bubble pulse arrivals) measured on the 16 channel IoA array. Individual broadband receiv

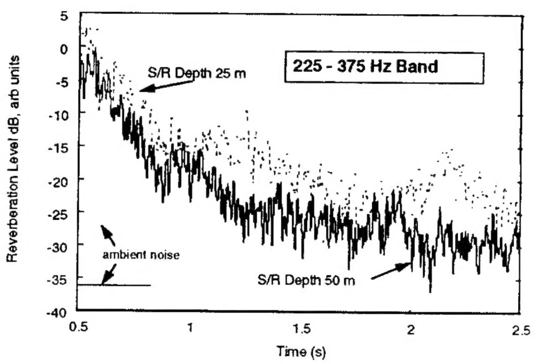


Fig.7a Low frequency reverberation for two different source/receiver depths [APL/UW]

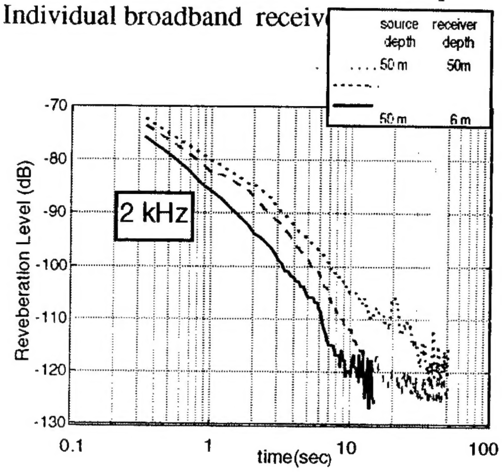


Fig. 7b High frequency reverberation for three source/receiver depths [IoA]

each channel are shown on the top left with a depth averaged signal shown at the bottom. Waveguide dispersion can be seen in the data. The depth averaged signal is shown filtered in 1/3 octave bands on the right. The dispersion is readily apparent. Figure 9 shows arrival structure at 10 km for a matched filtered 290Hz signal measured on the 16 channel IoA array. The first three modes are time separated and the mode shapes can be inferred. Figure 10 shows explosive shot arrival data measured at 3.7 km measured on the 16 channel ARL/UW suspended array for source depths of 50m (below the thermocline) and 7 meters (above the thermocline).

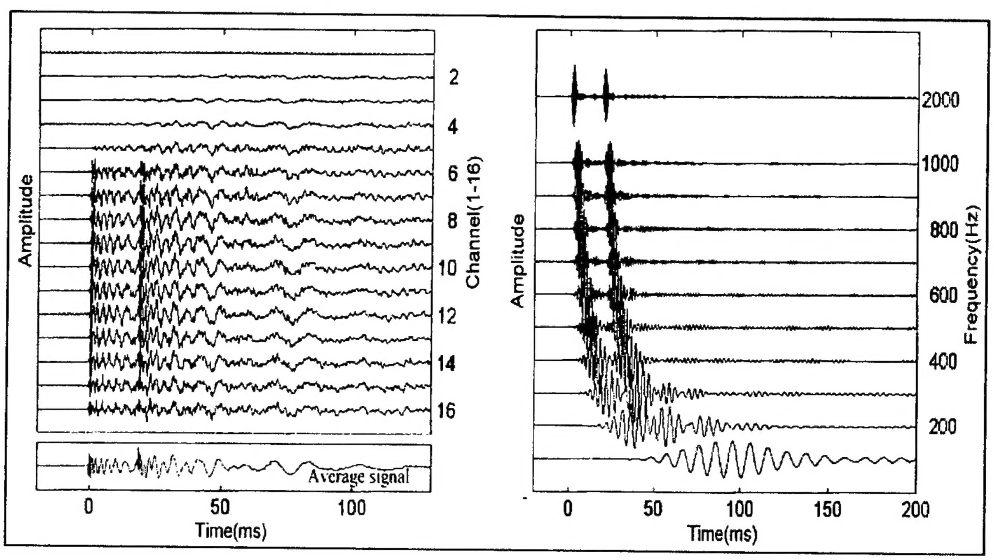


Fig.8 Arrival structure of explosive pulse at 25km. Left: Broadband signal vs depth and depth averaged signal.. Right: Average signal filtered in 1/3 octave bands

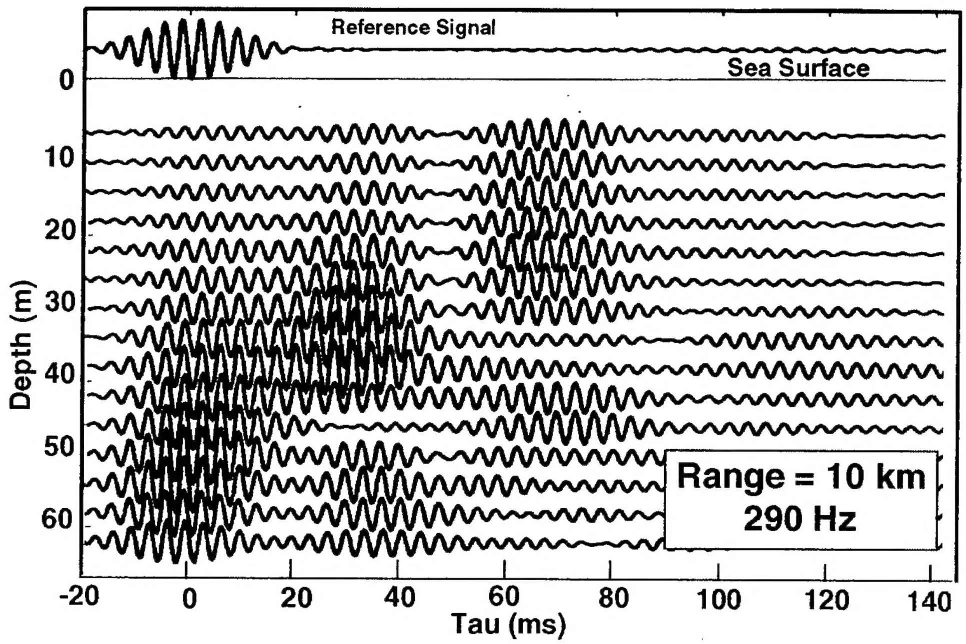


Fig. 9 Match filtered 290 Hz M-Sequence signal at 10 km

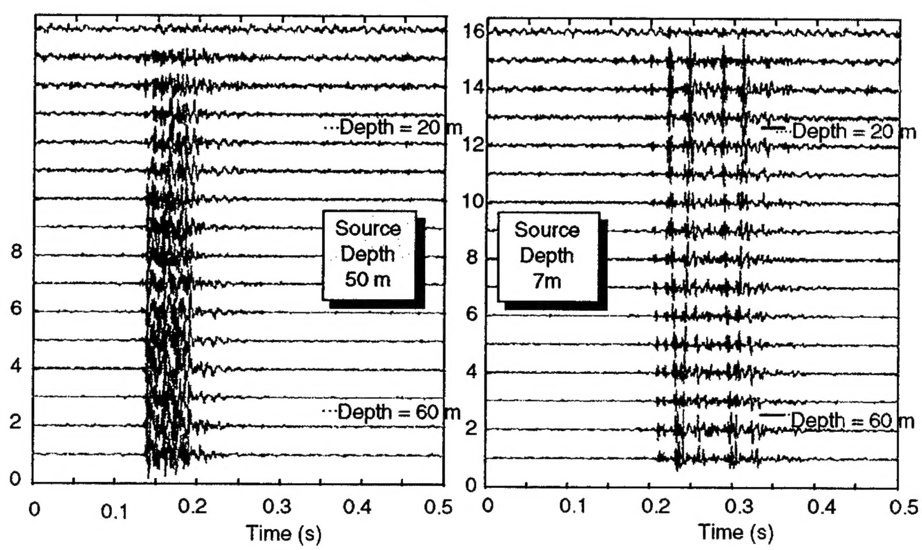


Fig. 10 Explosive shot arrival data measured at 3.7 km measured on the 16 channel ARL/UW suspended array for source depths of 50m (below the thermocline) and 7 meters (above the thermocline).

The overall quality of the acoustic data was quite good. However, much of the thermistor data was compromised by insufficient flotation so considerable processing will be required to remove the effects of currents from the data. The prospects for this experiment validating Zhou's internal wave hypothesis depend on success in processing array motion from the thermistor data.

The Yellow Sea '96 experiment demonstrated some of the potential benefits of China-U.S. cooperation in shallow water acoustic research. It also highlighted the desirability of the Yellow Sea as a test bed for acoustic and internal wave research. The Yellow Sea '96 experiment was formulated as a pilot effort for future research. Preliminary results appear interesting and of high quality. The Yellow Sea '96 experiment should inspire more ambitious cooperative experiments in the future.